Multi-Sensor Snow Data Assimilation

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Project Summary

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Problem Statement: MODIS, AMSR-E, and GRACE all provide observations that are relevant to snow water equivalent mapping, each with significant advantages and disadvantages.

Hypothesis: Global fields of SWE can be produced with greater accuracy than previously seen by simultaneously assimilating MODIS snow cover, AMSR-E ~~SWE~~ *radiance data*, and GRACE terrestrial water storage observations within a sophisticated land surface model.

Team:

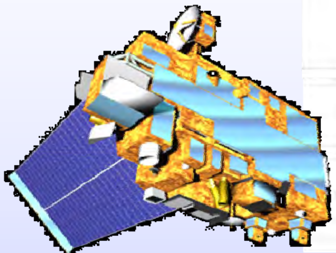
- NASA/GSFC: Matt Rodell (PI), Ed Kim, Rolf Reichle
- U. Texas: Liang Yang (Co-PI), Yongfei Zhang, Yonghwan Kwon
- Johns Hopkins: Ben Zaitchik

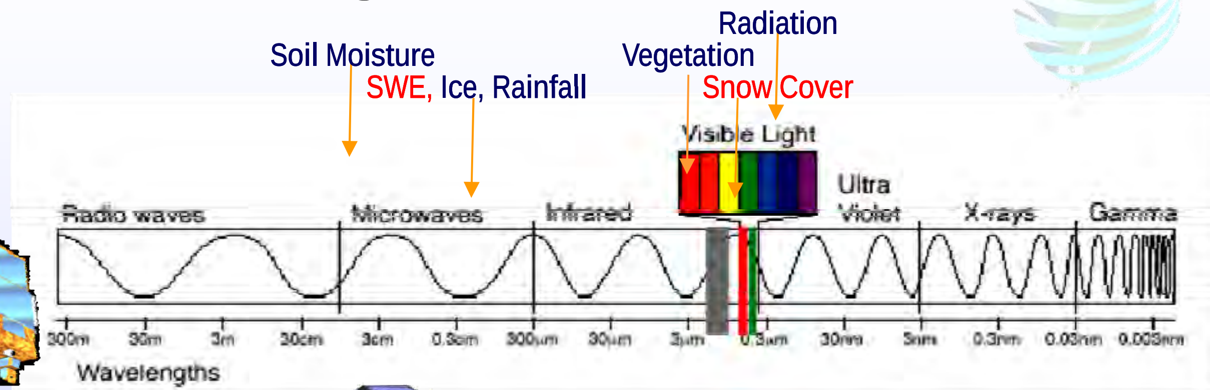
Timeline: Beginning year 3

Remote Sensing of Snow

Aqua: MODIS, AMSR-E

Terra: MODIS





MODIS provides high resolution snow cover data but not SWE; AMSR-E provides SWE data but with significant errors where snow is deep or wet

GRACE

GRACE provides changes in total water storage, which are dominated by SWE at high latitudes and altitudes, but at very coarse resolution

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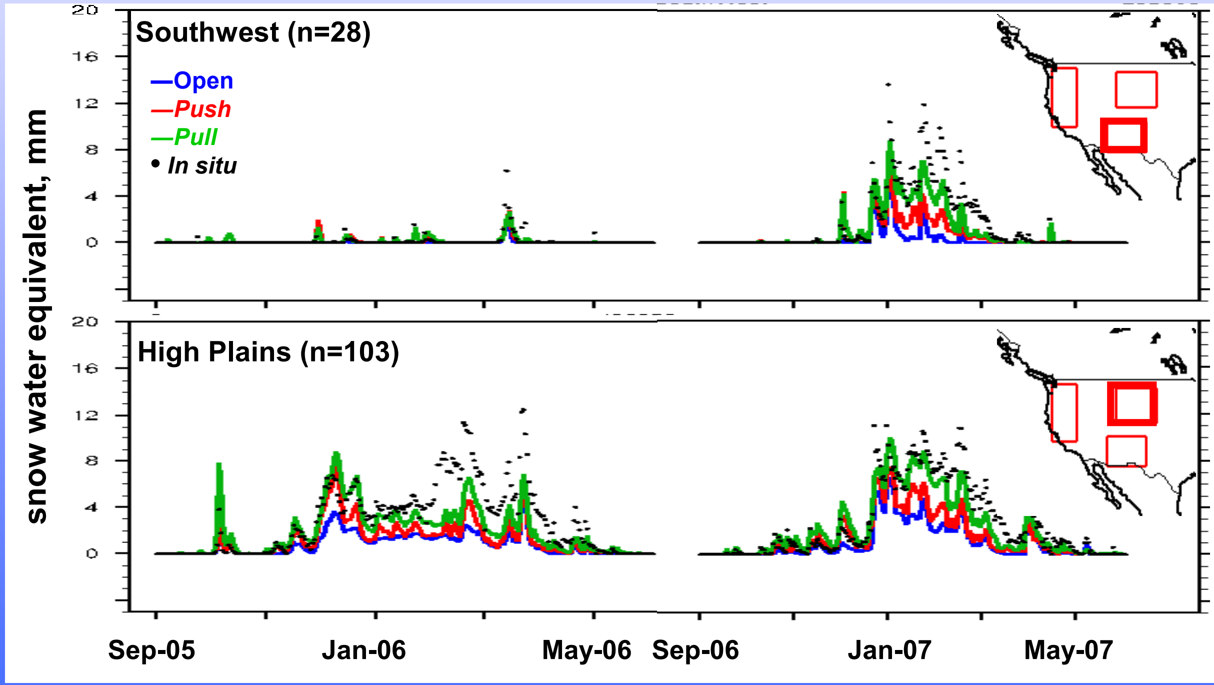
Advanced Rule-Based MODIS Snow Cover Assimilation

<u>Foreward-looking "pull" algorithm</u>

- Assesses MODIS snow cover observation 24-72 hours ahead
- Adjusts temperature to steer the simulation towards the observation
- Generates additional snowfall if necessary
- Improves accuracy while minimizing water imbalance



Zaitchik and Rodell, J. Hydromet., 2009

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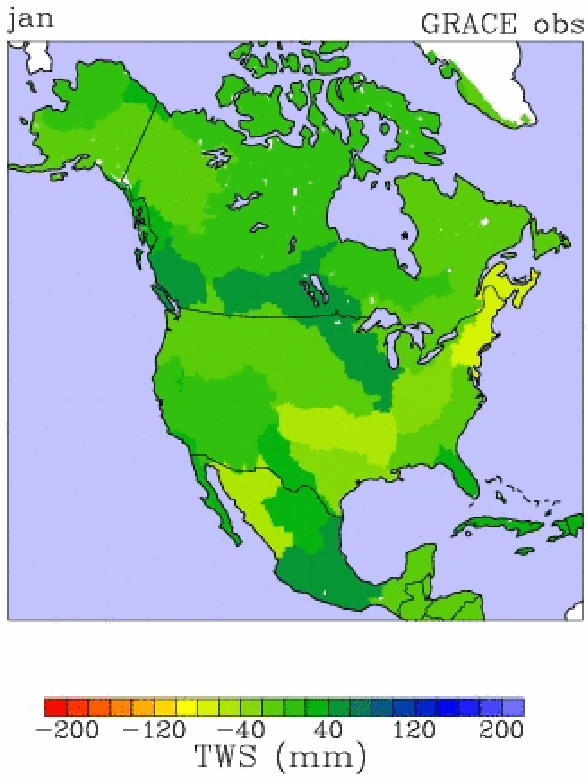
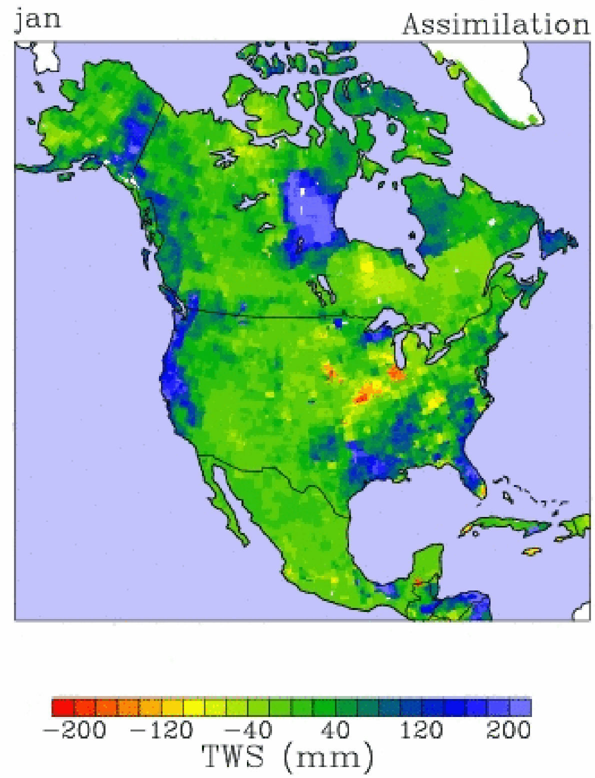
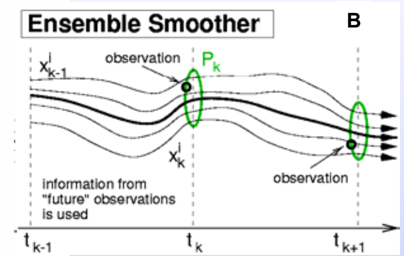
GRACE Data Assimilation

GRACE water storage, mm
January-December 2003 loop



Model assimilated water storage, mm
January-December 2003 loop





Monthly anomalies (deviations from the 2003 mean) of terrestrial water storage (sum of groundwater, soil moisture, snow, and surface water) as an equivalent layer of water. Updated from *Zaitchik, Rodell, and Reichle, J. Hydromet., 2008.*

From scales useful for water cycle and climate studies…

To scales needed for water resources and agricultural applications

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AMSR-E Radiance Assimilation

Atmospheric Forcing

CLM4
Snow physical model
(Density, Grain size,
Thickness, temperature,
liquid water content)

Microwave Emissions
Model of Layered
Snowpacks (MEMLS)
Radiative Transfer Model

Modeled Tb

Update

Observed
AMSR-E
Radiance

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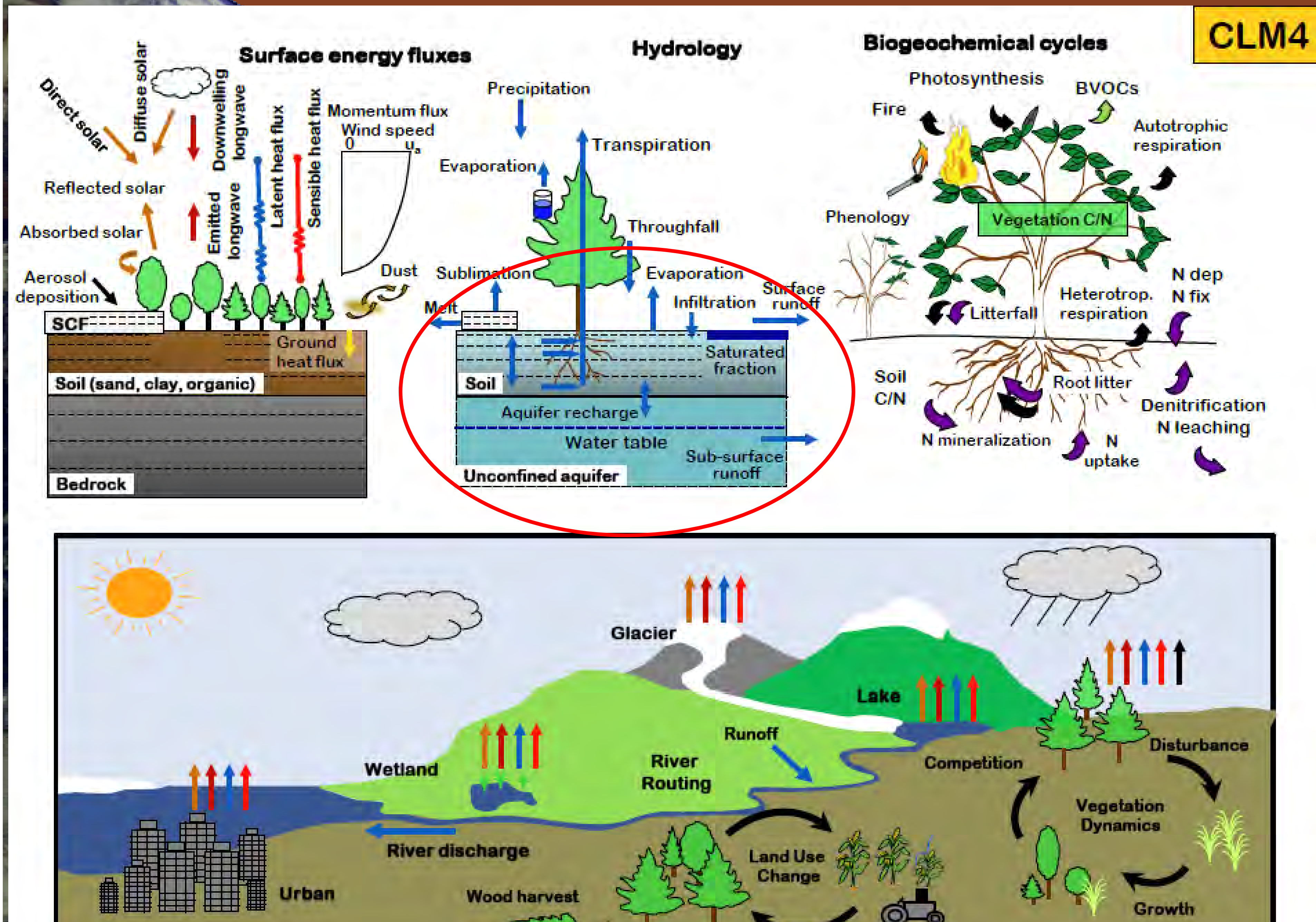
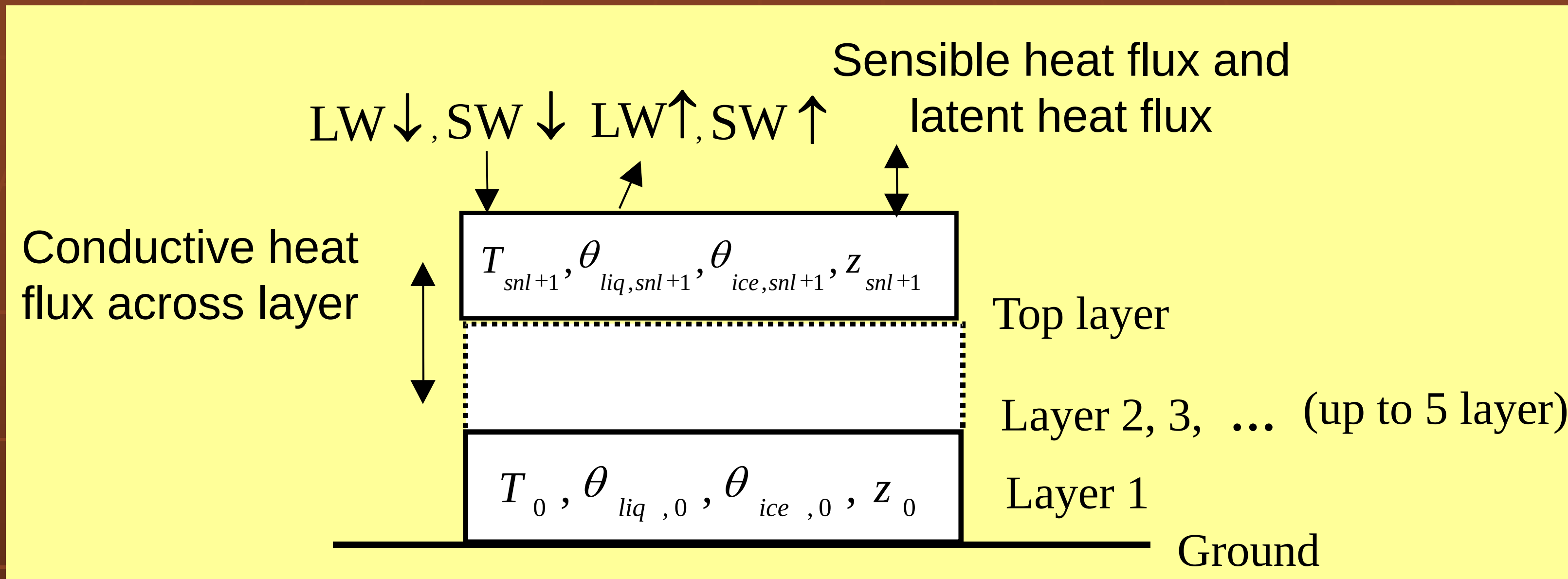


Co-Chairs: David Lawrence (NCAR), Zong-Liang Yang (Univ of Texas at Austin)

Multi-layer Snow Model in Community Land Model



$$C\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + \rho_{ice} L_f \frac{\partial \theta_{ice}}{\partial t} + S$$

Snowpack heat diffusion

$$G + LH + SH = LW_g + SW_g$$

Surface energy balance

$$X_{SWE,t} = X_{SWE,t-1} + P_t - Q_t - E_t$$

System function

Assessment of CLM4 Snow Output

CLM4 Configuration

- Offline (uncoupled) mode at 0.9° x 1.25° (latitude x longitude).
- Princeton meteorological forcing fields(Sheffield et al. 2006).
- 1948 to 1979 spinup

Evaluation Data:

1) MODIS/Terra daily snow cover fraction (Hall et al. 2002: MOD10C2; 0.05^{o} resolution; northern hemisphere; 2001 to 2010)
2) Interactive Multisensor Snow and Ice Mapping System (IMS) data (NOAA/NESDIS/OSDPD/SSD, 2004) (2001-2010)
3) Canadian Meteorological Centre (CMC) daily snow depth (Brown and Bransnett, 2010) and SWE estimates using the Sturm et al. (2010) snow densities (by Bart Forman) (1998-2010).
4) Snowpack Telemetry(SNOTEL) SWE and Cooperative Network (COOP) snow depth(1999-2010).

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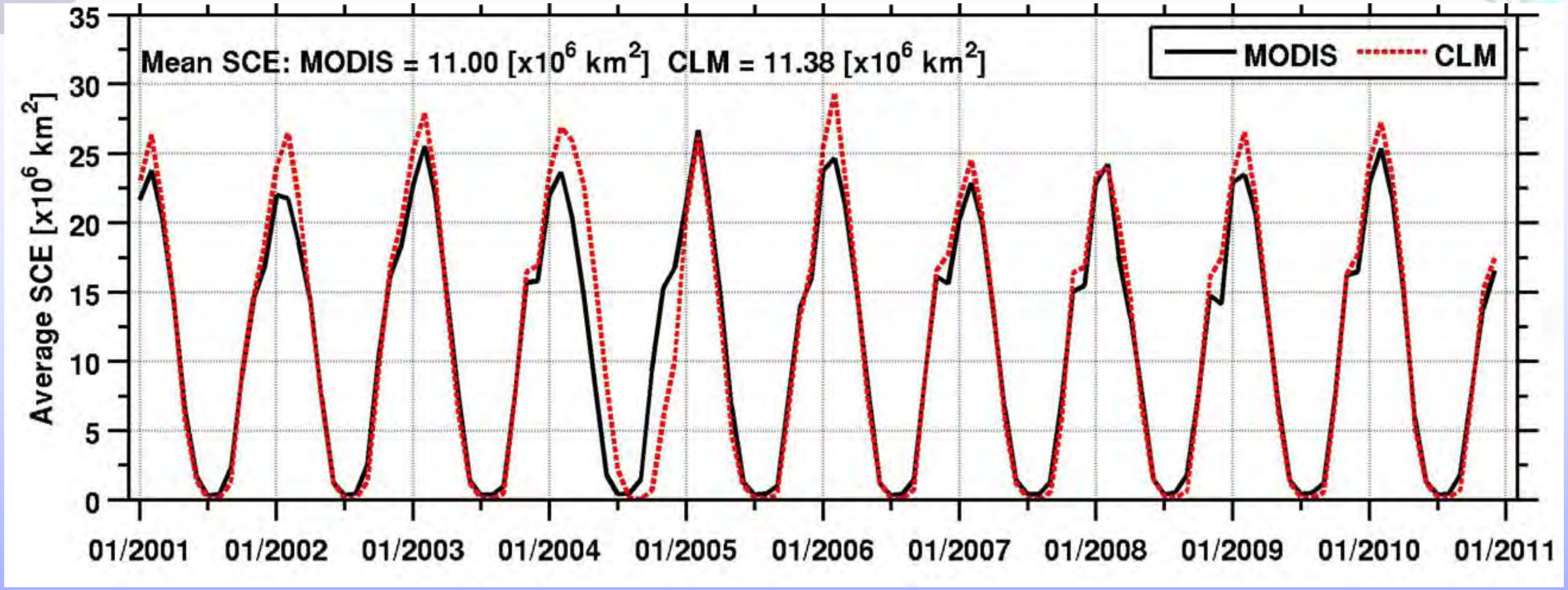
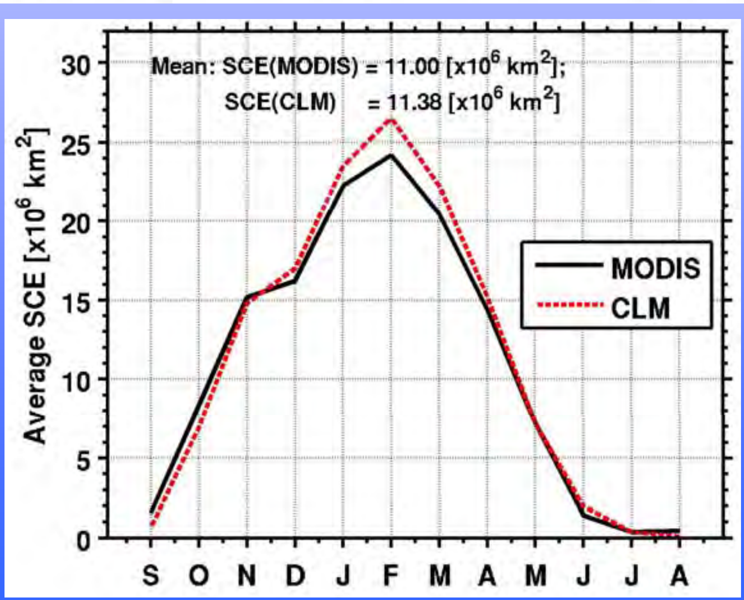
Comparison of CLM4 with MODIS SCF Observations



- Global (shown here) and regional comparisons indicate room for improvement at margins of snowpack
- Princeton-forced CLM4 tends to overestimate snow covered fraction with generally good agreement of phase



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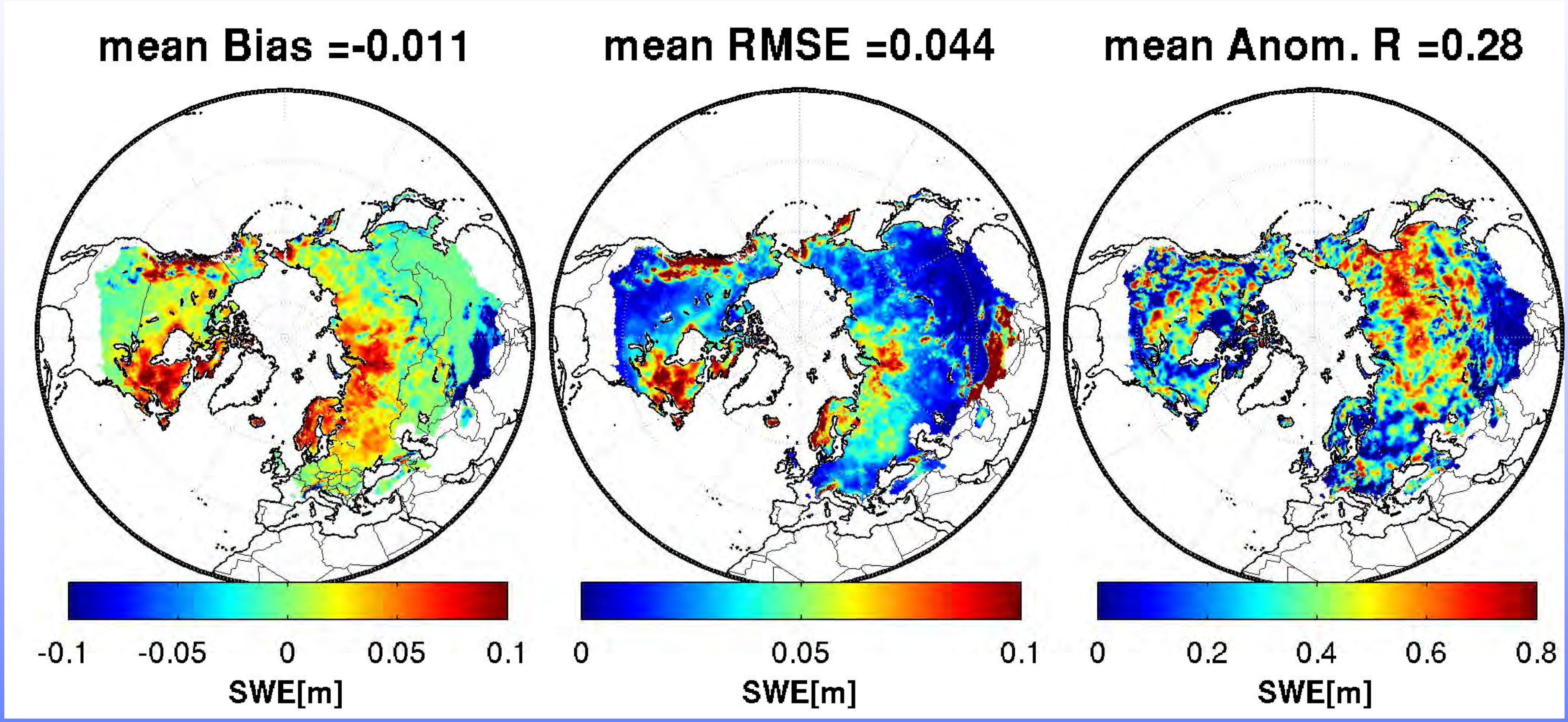
Comparison of CLM4 against Canadian Meteorological Centre SWE Product



- Large differences in some areas (CMC product should not be considered "truth")
- Modeled SWE expected to benefit from AMSR-E radiance assimilation in shallow snow areas and from GRACE assimilation in deep snow areas

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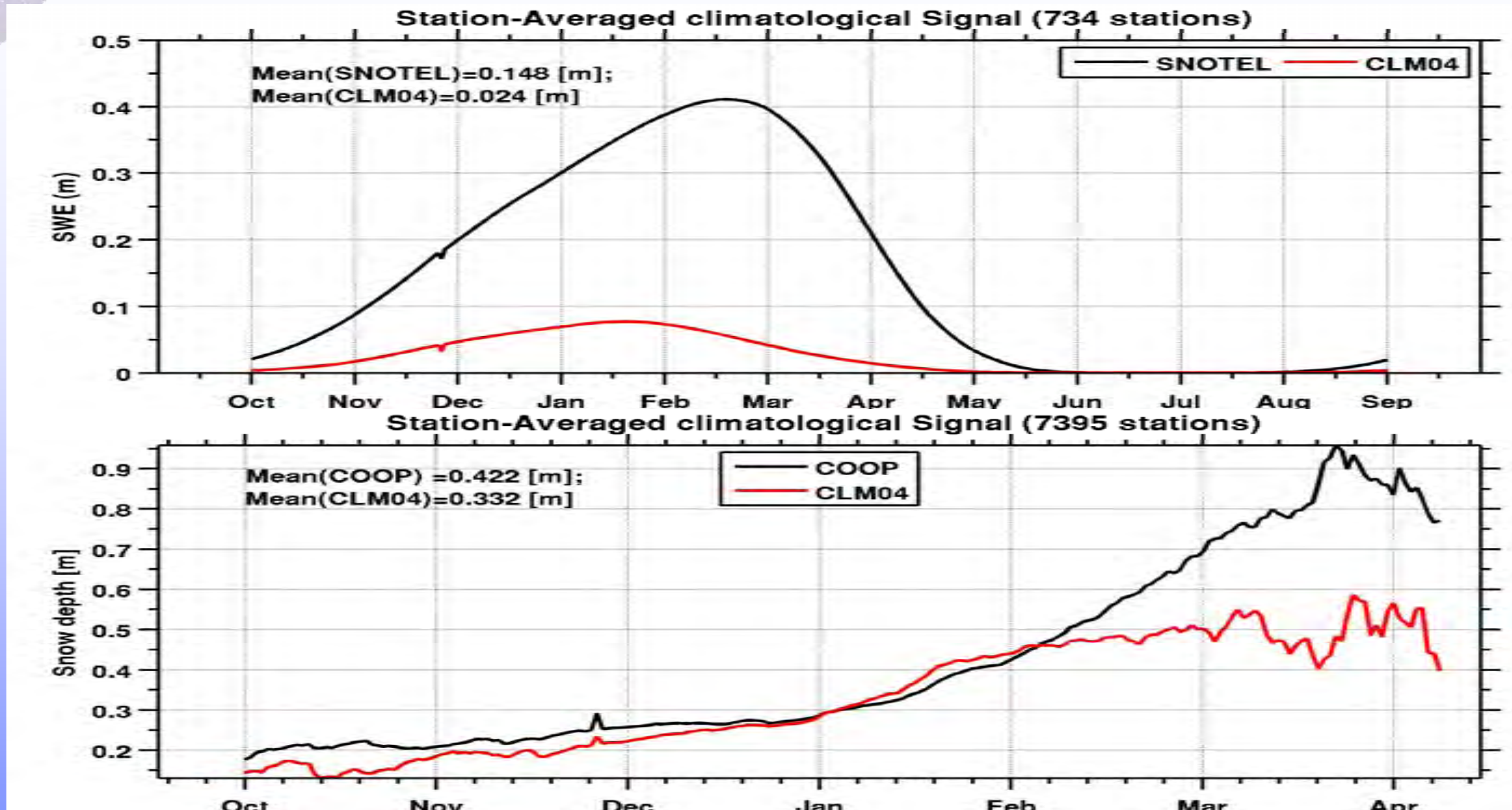
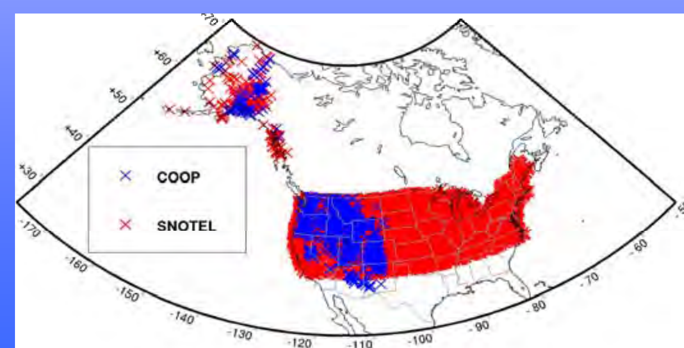
Comparison of CLM4 Against In Situ Observations



Metric	Units	SNOTEL (SWE)	COOP (Snow depth)
Bias	[m]	0.225	0.007
RMSE	[m]	0.286	0.200
Anomaly R	[-]	0.24	0.29



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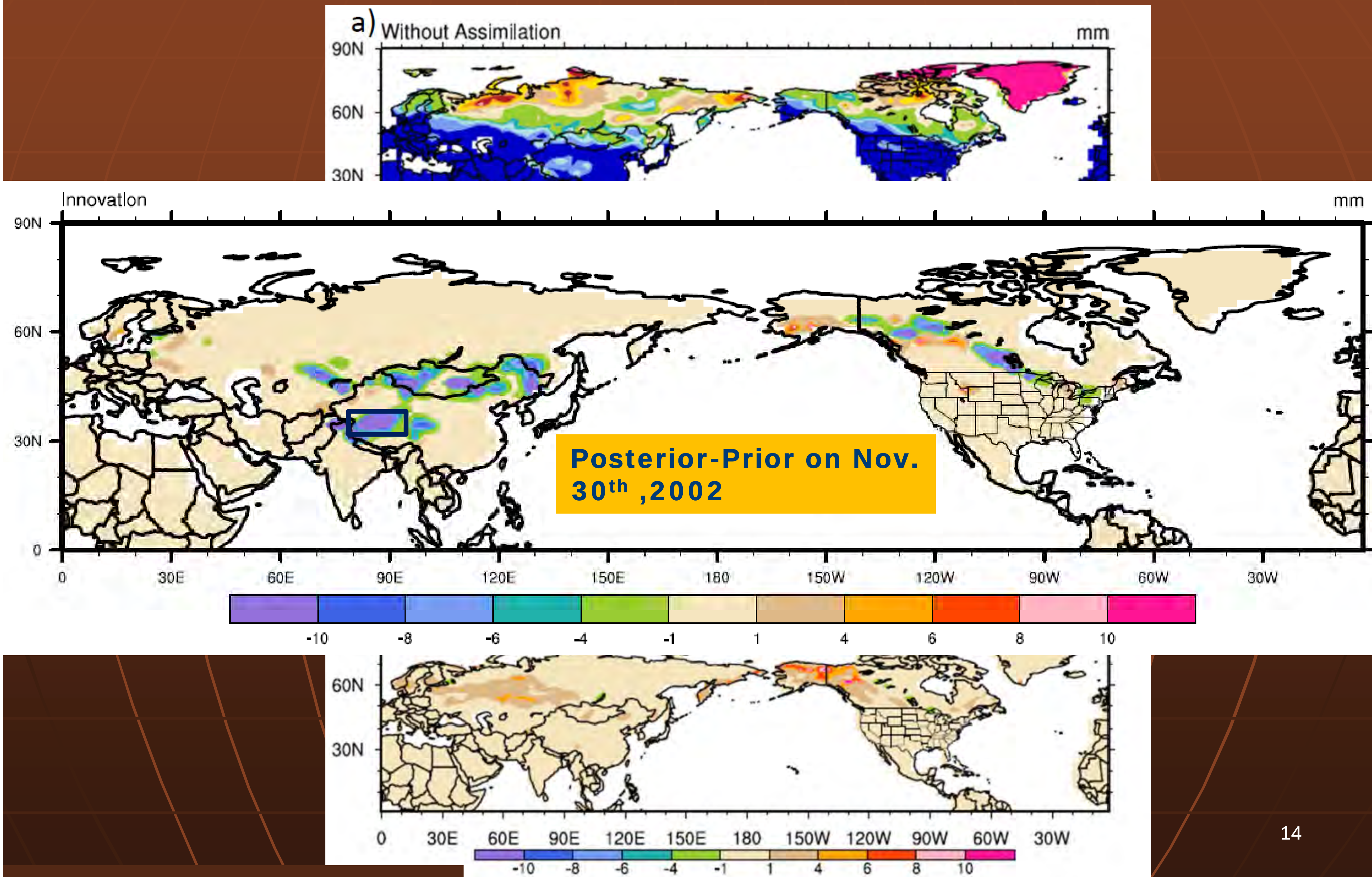
Data Assimilation Research Testbed (DART)

- A comprehensive data assimilation software environment
  - http://www.image.ucar.edu/DAReS/DART
  - developed and maintained by Jeff Anderson’s group at NCAR
  - used by both modelers and observational scientists to easily explore different data assimilation methods, observations, and models
  - linked to atmospheric models (WRF, CAM4) and oceanic models
  - being recently linked to CLM4 (UT and NCAR collaboration)
- Community efforts for data assimilation

NCAR IMAGe: Data Assimilation Research Section

Monthly Ensemble Mean SWE



Zhang et al., 2011, AGU Fall Meeting

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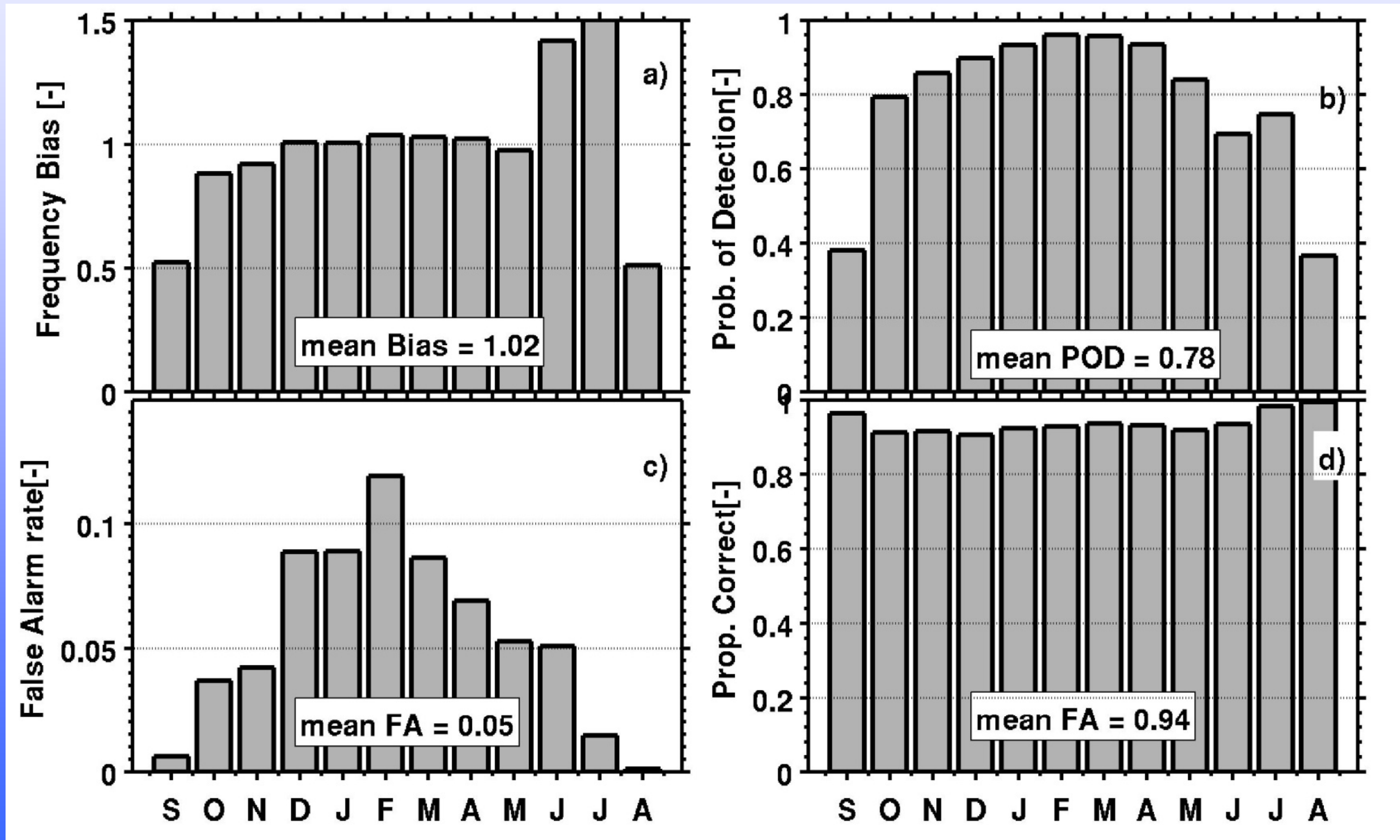
BACKUP SLIDES

Comparison against MODIS SCF Observations

b) Categorical analysis



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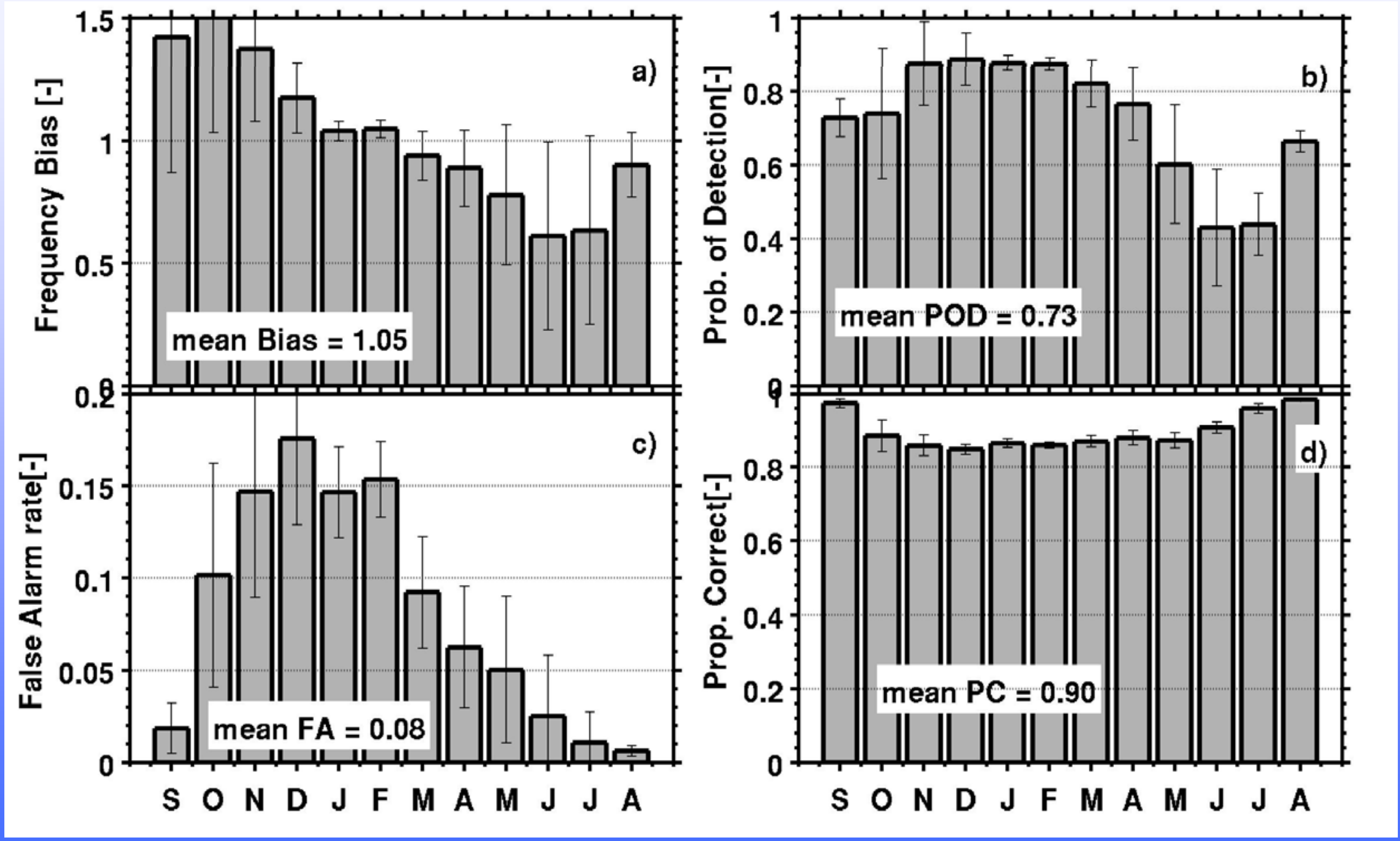
Comparison against IMS Product



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Community Land Model

- Evolved from CLM3.5 (released in 2008). CLM3.5 improves over CLM3 (released in 2004)
  - Surface runoff (Yang and Niu, 2003; Niu, Yang et al., 2005)
  - Groundwater (Niu, Yang, et al., 2007)
  - Frozen soil (Niu and Yang, 2006)
  - Canopy integration, canopy interception scaling, and pft-dependency of the soil stress function
- CLM4 (released in 2010) improves over CLM3.5
  - Prognostic in carbon and nitrogen (CN) as well as vegetation phenology; the dynamic global vegetation model is merged with CN
  - Transient landcover and land use change capability
  - Urban component
  - BVOC component (MEGAN2)
  - Dust emissions
  - Updated hydrology and ground evaporation
  - New density-based snow cover fraction (Niu and Yang, 2007), snow burial fraction, snow compaction
  - Improved permafrost scheme: organic soils, 50-m depth (5 bedrock layers)
  - Conserving global energy by separating river discharge into liquid and ice water streams

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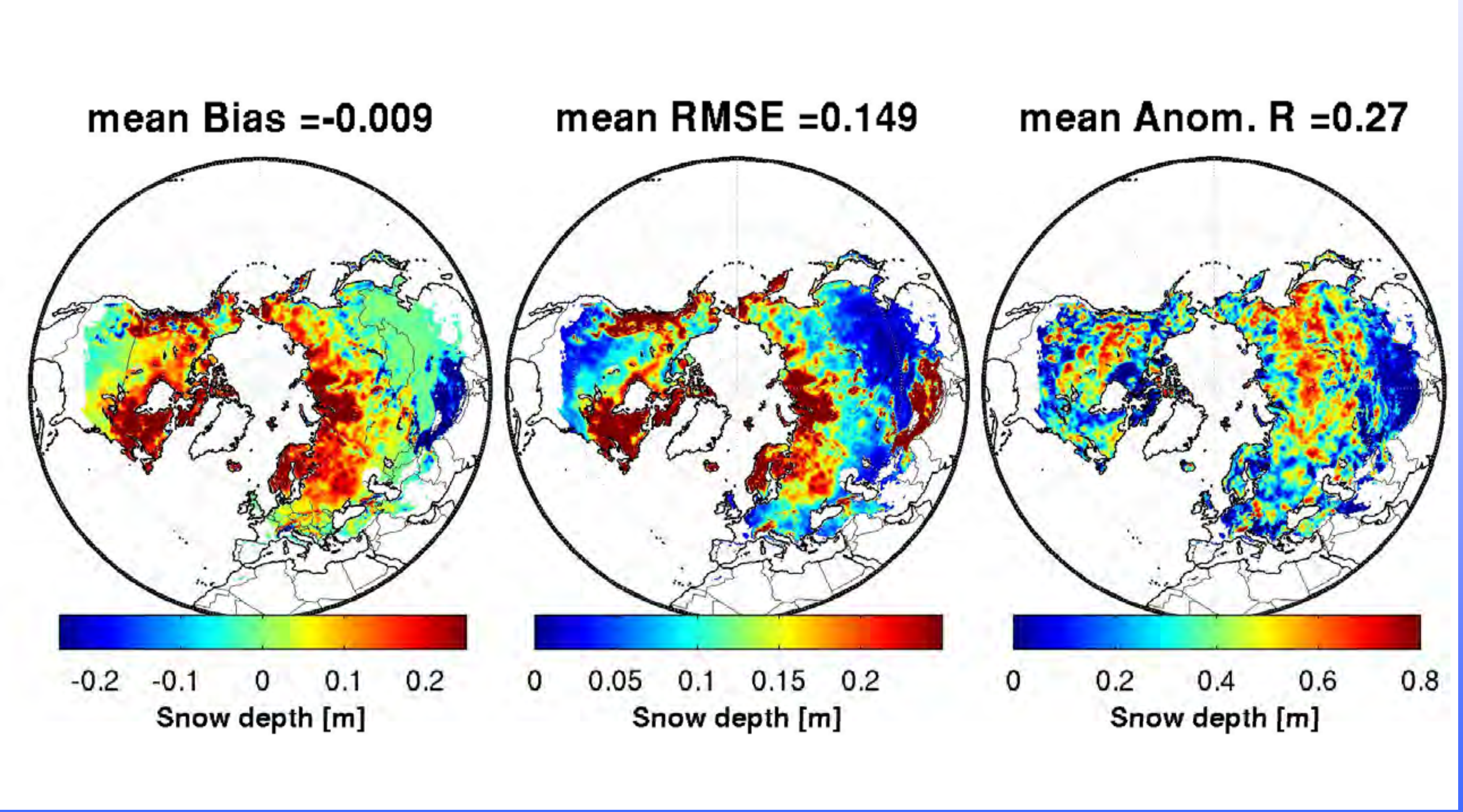
JACKSON

Co-Chairs: David Lawrence (NCAR), Zong-Liang Yang (Univ of Texas at Austin, 2008-2013)

Comparison against CMC Product

a) Snow depth



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